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Low Cost Air Quality Monitoring: Comparing the energy consumption of an Arduino against a Raspberry Pi based system

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Air pollution is one of the great challenges facing modern cities. According to the World Health Organization (WHO), 80% of people living in cities with air quality monitoring facilities are living in conditions where the quality of the air is well beyond the limits set out in the air quality guidelines. As more and more people are projected to move into urban areas by 2050, this problem is going to keep on increasing. A possible solution could be the advent of Smart Cities. One of the objectives of Smart Cities is to provide a better living environment to its inhabitants. With the Internet of Things providing easily deployable, low power, low cost air quality monitoring sensors and the resources to process the huge amount of data collected, this objective could be reached. In this paper, we propose an evaluation of the power consumption of two low cost air quality monitoring systems – one based on an Arduino and the other on a Raspberry Pi system. The air quality systems proposed are based on off-the shelf hardware and are easy to assemble and maintain. The proposed systems use Bluetooth Low Energy (BLE) to transmit data while being collected through a mobile app on a smartphone. The data was collected for five days and it was found by performing an ANOVA on the power consumption that there was a significant difference in the mean energy consumption of the two systems.

CCS Concepts: • **Hardware → Power and energy**; **Power estimation and optimization**;

Additional Key Words and Phrases: air quality, monitoring, smart cities, IoT, energy consumption

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1 INTRODUCTION

In recent years, air pollution has come in the front line discussion within the global community. The question of what causes the increase in air pollution and if climate change will affect earth's habitats is regarded by some as a serious threat to human health and the environment. Smart cities could help to create a healthier environment and help to improve the quality of life of people around the world. IoT-powered smart cities could enable cities to monitor the environment and enable healthier living conditions [33, 75]. In the SmartSantander project [50], the monitoring of pollutants around the city was one very important aspect of the proposed smart city. IoT has enabled the deployment of a large number of air quality monitoring sensors and if a pollution

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hotspot was detected, more accurate sensing devices were deployed to the area [51]. Air pollution in recent years, has been a matter of concern to the world's environmental scientists and researchers. Moreover, the recent focus has been on how to combat the emission of these dangerous gases into our environment and the devastating effects it has on humans' health and the ecosystem [55].

Air pollution can be categorized into visible and invisible air pollution. Visible pollutants are caused by particulate matter whilst the invisible pollutants are the gases that are released into the atmosphere when fossil fuels are burned [58]. Furthermore, the pollution that comes from the increase in urbanization and industrialization are known to be primary pollutants.

The paper is divided as follows. Section 2 provides the background to air quality, and measurement systems. Section 3 discusses the methodology adopted. Section 4 provides an overview on the Data collection and Section 5 discusses and analyses the results obtained. Finally Section 6 concludes the paper.

2 BACKGROUND

2.1 Causes of Air Pollution

According to [64], half of the world populations currently reside in urban areas and by 2030 the urban population will increase by about 5 billion. This increase will result in an increase in traffic, trucks, airplanes, trains and manufacturing industries which all rely heavily on burning of fossil fuels. Combustion of these fuels emits hazardous gases that are damaging to our environment, causing various health issues (sometimes may even lead to death) and a reduction in the sense of smell [25].

Agricultural activities are another major contributor to air pollution. Due to the increase in the utilization of fertilizer, by farmers and the techniques in which pests and insects are controlled (by the use of pesticides and insecticides) and mechanized farming. Results in the increase in emission of harmful chemicals into the air [53].

Mining of minerals from the earth also releases dangerous chemicals and dust particles to the air, causing huge air pollution and devastating effects to the environment. Increase in atmospheric temperature, Carbon dioxide (CO_2) and O_3, amongst other pollutants also contributes greatly to climate change.

2.2 Major Air Pollutants

There are several hazardous gases that pollute the air when emitted or released into the atmosphere whether in small or large amounts, but become more dangerous to life if highly concentrated. The major and more concerning variants are Carbon Monoxide (CO), Carbon Dioxide (CO_2), Ozone (O_3), Nitrogen Dioxide (NO_2) and Sulfur Dioxide (SO_2) and particulate matters (PM_{10} and $PM_{2.5}$).

2.2.1 Carbon Dioxide (CO_2). CO_2 a member of the greenhouse gas family, it is harmless at a concentration less than 0.05 percent. Plants and trees depend on this gas for metabolism and through the process of evapotranspiration, plants release natural air conditionals into the atmosphere which cools our environments [11]. A study by Carnegie Institution for Science reviews that increase in concentration of CO_2 decreases plants cooling power (evaporative cooling by plants) [11], and also could have a profound effect on global climate [37, 62]. In recent years, the concentration CO_2 have been on the rise, a study by [35], shows that from 315 ppm in 1959 to an average approximately 385 ppm in 2008. Current projection of atmospheric concentration of CO_2 will continue to rise from 500 to 1000 ppm by the year 2100 [30].

The IPCC 2007 report states that there has been an annual increase in CO_2 emissions globally, to about 80 % from 1970 to 2004, and that about 56.6 % of the annual emissions of CO_2 comes from the combustion of fossil fuels and 17.3 % of it are from agricultural activities [30]. In 2015, an

IPCC[31] report stated that CO_2 made up about 76% of the total annual anthropogenic Green House Gases(GHG) emissions in 2010. Studies have shown that CO_2 is a major pollutant and contributor to global warming.

2.2.2 Carbon Monoxide (CO) . Carbon monoxide is one of the most dangerous gases in our environment. It easily binds to hemoglobin in the blood which prevents tissue oxygenation. This gas is odorless, colorless and tasteless which makes it more poisonous (often refer to as silent killer). It is produced by incomplete combustion of fossil fuels. The increase in urbanization and industrialization also increases the rate at which CO is emitted to the atmosphere which could be deadly and pose more health risks [74].

2.2.3 Particulate Matter (PM_{10} and $PM_{2.5}$). As a visible air pollutants are in form of solid particles or fluid droplets emitted to the atmosphere, a number of which are dangerous. Some are so small that it can only be detected via an electron microscope [65]. PM particles are complex mixture of both organic and inorganic particles (like dust, soot, smoke, liquid droplets and some others), that are emitted directly or indirectly formed. PM are directly emitted into the air through the combustion of fuels, mineral mining, wind and construction sites. It indirectly forms in the atmosphere through a complex reactions of other pollutants like nitrogen oxides and sulfur dioxides. Particles comes in various sizes and shapes, based on size, PM are categorized into two main groups coarse particles (PM_{10}) and fine particles ($PM_{2.5}$)[24]

PM particles could cause some serious health problems when inhaled [65]. $PM_{2.5}$ particles or less can go deep into the lungs, some even into the bloodstream and also cause reduce visibility (haze) [19, 44].

2.2.4 Nitrogen Dioxide (NO_2). Studies shows that the emission of nitrogen oxides (NO_X)in 2004 stand at 7.9% and 6.2% in 2010 [30, 31]. NO_X also a pollutant occurs when nitrogen reacts with oxygen and NO_2 arises through the oxidation of nitrogen oxides by oxygen in air. Also, its emission comes mostly from agricultural activities and combustion of fossil fuels [30]. An increase in urbanization and industrialization serves as a major source of NO_2 [74]. This pollutant has devastating effects to our environment, when it reacts with other pollutants in free space, the interaction will produce PM particles and ozone (O_3) . This pollutant also contributes to global warming by producing O_3 [69].

2.2.5 Sulfur Dioxide (SO_2). SO_2 a toxic gas high in concentration in the atmosphere than other sulfur oxides (SO_X) gaseous (such as SO_3). Have devastating effects on both the environment and health. The largest source of this toxic gas is from fossil fuels combustion. Also, it emits into the atmosphere naturally by volcanic activities and through mineral mining (extracting metal from ore) . When react with other pollutants in the atmosphere will produce fine particles ($PM_{2.5}$) [66].

2.2.6 Ozone (O_3). Ozone is a gas that is produced and very reactive in the presence of sunlight. It is also produced during the depletion of the ozone layer which is the main source of this gas. O_3 exists in two layers of the atmosphere, at stratosphere level (upper layer known as the ozone layer), it protects the earth from dangerous UV radiation [1]. In the lower atmosphere, it is a toxic pollutant which can have a devastating effect on health and the environment in high concentration, and it's a major element of smog [68].

2.2.7 Effects on Human Health. The review by World Health Organization (WHO) indicates that about 3.7 million premature deaths globally in 2012 were a result of diseases caused by Ambient Air Pollution (AAP) both in urban and rural areas. It further shows that as of 2014, about 80% of the global population were residing in areas far below the WHO air pollution guidelines [70]. In high concentration or prolonged exposure to air pollutants could cause various health issues as highlighted in Table 1.

Table 1. Air Pollution Effects on Health at high Concentration

Air pollutants	Effects on health at high concentration
O_3, NO_2, and SO_2	Asthmatic patients and children are susceptible to these gases. When inhaled cause a reduction in lung function growth, lung diseases and worsen chronic bronchitis. Also, make humans open to respiratory tract infections [1, 74]. Like SO_2 and NO_2 which interact with other pollutants in the atmosphere to form fine particles that reduce visibility [44, 69].
CO	At a very high concentration this poisonous gas reduces the level of oxygen that gets to the brain and heart [74], this can be deadly. Also, can cause unconsciousness, dizziness and even death. Increases symptoms of heart related diseases.
CO_2	At a very high concentration of this gas in the blood could cause death and permanent injure. However, till the concentration of CO_2 in the atmosphere gets to approximately 15000 ppm it cannot affect human health [54], which indicates about 30 times more than the current concentration as estimated by IPCC [31].
PM_{10} and $PM_{2.5}$	High concentration of PM with a diameter of 10 micrometers and smaller exposes human to respiratory diseases and lung cancer [44].

2.2.8 Effects on the Environment. Very high concentration of SO_2 in the atmosphere forms sulfuric acid, which then drops to the earth as acidic rain that can harm aquatic life and vegetation. Acid rain destroys the leaves of trees and plants just as high concentration of CO_2 does [35]. Thus, reducing the cooling power of plants and trees which in turn increases global warming [62]. The soil chemistry is affected by acidic rain which can cause a decrease in crop productions. NO_2 reacts with other pollutants in free space will produce O_3.

2.3 Air Quality (AQ)

Air quality is the condition of the air in the atmosphere either in clean state or polluted state. Good air quality promotes total well-being of life (both for humans, vegetation and wildlife) and the climate. The quality of air is being determined by measuring and taking the average of pollutants concentration in the atmosphere. Air quality either ambient or household air quality is a global issue. Government agencies use Air Quality Index (AQI) to indicate how the quality of air is at a particular time and location, the higher the number the more polluted the air.

2.3.1 Air Quality Index (AQI). AQI is a number used to measure pollutants concentration level in the atmosphere. National Ambient Air Quality Standards (NAAQS) is a standard set by EPA (Environmental Protection Agency, USA) to control pollutants level and protect public health. As shown in Table 2 the lower the number the healthier the air, while the higher the number the more dangerous the air is on human health. For example, air quality level for AQI less than 50 is of high quality with no health effect, while AQI above 300 indicates that the air is highly dangerous and would have a severe health effects on human and even death.

Table 2. AQI level and Health Implications [71]

AQI	AQI Level	Air Pollution Level	Effects on Health
0 – 50	1	Highest quality	Clean and clear air no pollution
51 – 100	2	Good quality	Accepted, but some pollutants pose light health concern to people usually sensitive to air pollution
101 – 150	3	Moderate	Bad for people in sensitive group
151 – 200	4	Unhealthy	Everyone is affected will have effects on the respiratory system and the heart
201 – 300	5	The air is severely polluted	More symptoms
Above 300	6	Very dangerous	Severe symptoms and disease

2.4 Air Quality (AQ) Monitoring Systems

With the increase in urbanization, being one the of the main source of air pollution, the need to assess real time air quality information with accuracy is vital for urban planning [20]. Also, the data serves as an input for environmentalist and scientists in order to improve health related applications and government agencies to take precise decisions [61]. A lot of research have been carried out in AQ monitoring and analysis. In this section, works related to research area with respect to energy efficiency are discussed.

2.4.1 Fixed Monitoring Systems. A high performance geographic information system (HiGIS) based monitoring systems were proposed for processing and visualization of AQ data by [61]. The authors' focus was on map visualization of AQ information and spatial resolution. The system implemented main-memory database and spatial database for fast processing [36], of AQ data and real – time map visualization with geographic information system (GIS) technology [8]. But, little attention was paid on data collection, so data accuracy is an issue. This system is expensive and the energy consumption is high. The gas discrimination of CO_2 in an Air-Conditional system for the observation of AQ was presented in [52]. It describes the sending out data via the web. [3], presented OpenSense AQ monitoring system based on open sensor networks. A review by [9], shows that the selected Wireless Sensor Network (WSN) projects which covers fixed, vehicle and mobile systems still lacks in data accuracy, spatial and temporal resolution. The projects reviewed by Breitegger and Bergmann are OpenSense [3], CITI-SENSE [12, 13], and CamMobSense [41].

2.4.2 Low-Cost Monitoring Systems. In [4], Ali et al. proposed a low cost AQ monitoring systems for schools in smart cities. The focus of the system is to monitor and report the concentration level of CO and NO_2 within the school environment [4]. The proposed system is based on low cost sensors and, the ZigBee protocol and XBee technology.In [5], Behr et al. proposed a smart helmet for miners and the Zigbee protocol was used to send the collected sensor data to the server. A hierarchical AQ system was presented in [39], and a VOC monitoring system also based on ZigBee was reported in [45] .

In [73], the authors presented a smart AQ monitoring system which consisted of a smart sensor unit, a smartphone and a server. The sensor unit relay sensor data to the smartphone via Bluetooth technology (BT), the smartphone processes the data and displays the AQ information for the user before sending it to the server for map visualization on user's decision. A toxic monitoring systems based on BT was reported in [63], and [60], proposed AirSniffer, a smartphone based BT system for personal body area monitoring of AQ. Guan et al. presented mosaic system, a three-layer air monitoring system based on mobile sensor network [23]. The system is deployed on vehicles or carried around by users for data collection, then sends the data to a local server. The proposed system uses BT to communicate with the mobile phone app [22]. Brynda and Kosovy reported a mobile sensing unit for monitoring VOC concentration that uses BT to transmit sensor data to the mobile app for processing [10]. The app in turn forward the AQ information to a server. Firculescu and Tudose reported a low-cost mobile sensing system [21], the proposed system consists of a personal sensing network and public transport sensing network. The sensor nodes communicate with mobile phone via BT. Due to the short range and low transfer rate limitations in BT [67] and user decisions to forward the AQ information to the server, this system suffers from real time data collection and visualization and this can affect data accuracy.

In [32], a WSNs and infra-red gas sensor based approach was proposed for monitoring indoor AQ. The WSNs systems for monitoring AQ in room environment was also presented in [14] [17]. Techniques for reducing energy consumption in the sensor node were also described in [32]. Energy consumption also was the main focus in [34], the proposed environment monitoring system (EMS) consisted of a GPS module and a WSN for remote location monitoring for AQ. In 2004, Yan et al. presented a strategic approach for energy reduction in designing and implementing a WSNs [72]. A system for monitoring vehicle pollution was proposed in [40], the authors incorporated the use of Radio Frequency Identification (RFID) tags technology for detection of vehicles with high pollution level. A cloud based AQ detection analysis and prediction (AQDAP) was presented in [42]. The proposed system consisted of a sensor unit, a processing unit and a video analytic. The sensor unit sends data periodically to the processing unit, and the video analytic relay real-time footage of the vehicles carrying the system to the cloud.

Li, et al. presented a wearable monitoring system for accurate estimation of personal dose of UV rays [38]. The authors' focus was on personal UV monitoring. A numeric simulation tool (SimUVEx) was proposed in [48], for predicting personal UV exposure. The model is based on 3D exposure simulation and data from a monitoring station. Abas et al. reported a system for monitoring of ozone quality [2]. The proposed system comprises sensor unit and graphic user interface (GUI), the data logger sends data to the server via ZigBee protocol. In [43], a Fog computing based system which used CMOS sensor in smartphone camera for monitoring of UV was proposed. Also, the use of mobile phone camera for UV monitoring was suggested in [7, 15, 27–29]. However, smart phone based UV monitoring suffer from one major drawback i.e. high power consumption. The high energy consumption could be due to the fact that the phone was not built for this purpose and runs several applications at the same time. This could also affect the accuracy of the data [46].

2.4.3 Energy Consumption Comparison. A comparative analysis of energy consumption between BLE, ZigBee and ANT was presented in [18]. The main parameters used by the authors to compare the energy consumption of these protocols were based, on the time it takes a node to connect after waking up from a cyclic sleep. Based on their findings, the authors review that BLE consumes less energy followed by ZigBee. The authors further pointed out other factors that might affect energy consumption in these protocols, such as the variation in packet size, transmission range and hub parameters.

Moreover, a study by Siekkinen et al., showed that BLE really consumed less energy than ZigBee and with an appealing energy ratio per transmitted bit [59]. A comparison of energy consumption between Raspberry Pi model B and other classical computer was presented in [6]. The findings showed that raspberry Pi consumed less energy across the investigated 20 distinct operations, as compared to other classical computer systems. The authors suggested few techniques for further reduction of energy consumption on Raspberry Pi system. However, no research or study have been presented to address the comparison of energy consumption of low cost and low energy platforms to our knowledge. One of the most recent studies [26] on Low cost air pollution monitoring systems, reviewed protocols and enabling technologies whilst specifying many variations of Arduino and Raspberry Pi as options for data collectors, but lacked any coverage of energy consumption and instead focused on communications architectures. Another study on low cost air quality monitoring devices [16], which reviewed 41 research articles between 2012-2019 consisting of 35 unique device development projects considered performance of sensors, processor used, data storage and communication, with no particular emphasis on energy consumption. Another recent comprehensive study [49] reviewed indoor air quality monitoring systems for enhanced public health, only commenting on processor speed rather than energy consumption between Raspberry Pi and Arduino systems. It is clear therefore that a study on the energy consumed in low cost systems using these technologies is required.

3 METHODOLOGY

This research is aimed at comparing the power consumption of an Arduino 101 versus a Raspberry Pi 3 for effective air quality monitoring, using BLE for data transmission. This project is aimed at providing a solution in the area of AQ monitoring via experimental settings to observe the variation in power consumption of the chosen technology.

3.1 Low Cost and Low Energy Technology Overview

Micro-controller boards are the first choice for developing low cost and low power consumption monitoring systems. A micro-controller contains everything needed for it to control an external system. There are many types of micro-controller platform available but the most common platforms are Arduino and Raspberry Pi. These technologies have been the market leader in Internet of things (IoT) for the development of smart tracking and monitoring applications.

Both of these boards are low cost and ultra-low power boards, widely used for IoT applications. We have also equipped both boards with Grove expansion boards, giving access to the Grove Air Quality sensor.

3.2 Component Overview

Arduino 101 BLE (A101). This is an Arduino board incorporated with Intel Curie technology. This board consists of two cores, a 32-bit ARC architecture core and an x86 (Quark), both clocked at 32MHz. This board was designed specifically for the development of IoT applications. It also includes the CurieBLE library that enables communication and interaction with the board via smartphones and tablets.

Raspberry Pi 3 (RPI 3). This is the third generation of Raspberry Pi which features include built-in BLE and a 1.2GHz 64-bit quad-core ARMv8 CPU. We used the Raspbian OS[47].

Grove Base Shield v2 and GrovePi. These are Grove expansion boards that allow sensors with grove connectors to connect to either an Arduino (with Grove Base Shield v2) or Raspberry Pi (with a GrovePi). Grove sensors allow for rapid prototyping therefore eliminating the need to solder, by making use of a proprietary modular 4 pin connector system.

Grove Sensors. Two grove sensors were utilized to measure air quality and temperature. The air quality sensor is essentially a Carbon Monoxide sensor which also detects toxic gases such as alcohol, acetone, thinner, formaldehyde [56]. The temperature sensor's range is from -40°C to 125°C, and has an accuracy of ±1.500 °C [57].

Bluetooth USB Energy Meter (YZXStudio-ZY1270). YZXStudio-ZY1270 is a USB energy monitor. It monitors both the voltage and current used by devices it is attached to. The update rate is every 0.36s (HKJ, 2016).

4 DATA COLLECTION

Data collection was carried at two different indoor locations at ambient room temperature, during the winter months. The Arduino 101(see Figure 1) and the Raspberry Pi 3(see Figure 2) were assembled with their respective Grove boards and the sensors were connected. Both devices transmitted the data to a mobile phone app that was developed to accept data through a BLE connection.

The app immediately logs the data to Google Fusion tables in real-time via Wi-Fi or a Mobile Internet connection. Fusion tables are then used for data storage and analysis. The YZXStudio USB energy meter supplies power to the system and monitors the current consumption of the system every 0.36s. A console application was developed using C# to read the current from the energy meter via Bluetooth and log the data to a CSV file.

5 RESULTS

Table 3 presents the difference in energy consumption of the Arduino 101 system with and without the Grove shield and after establishing a BLE connection with the mobile app. The Bluetooth connection doubles the power requirements. Table 5 shows the daily average energy consumption of the system.

Table 4 presents the energy consumption of RPI3 system with and without GrovePi expansion board. It should be noted that the Bluetooth consumption remains comparably similar between the Arduino and Raspberry Pi, with both systems requiring around 0.3W of power. The average energy consumption of RPI3 system for the days of the experiment is shown in Table 6.

Fig. 1. Set up for Arduino 101

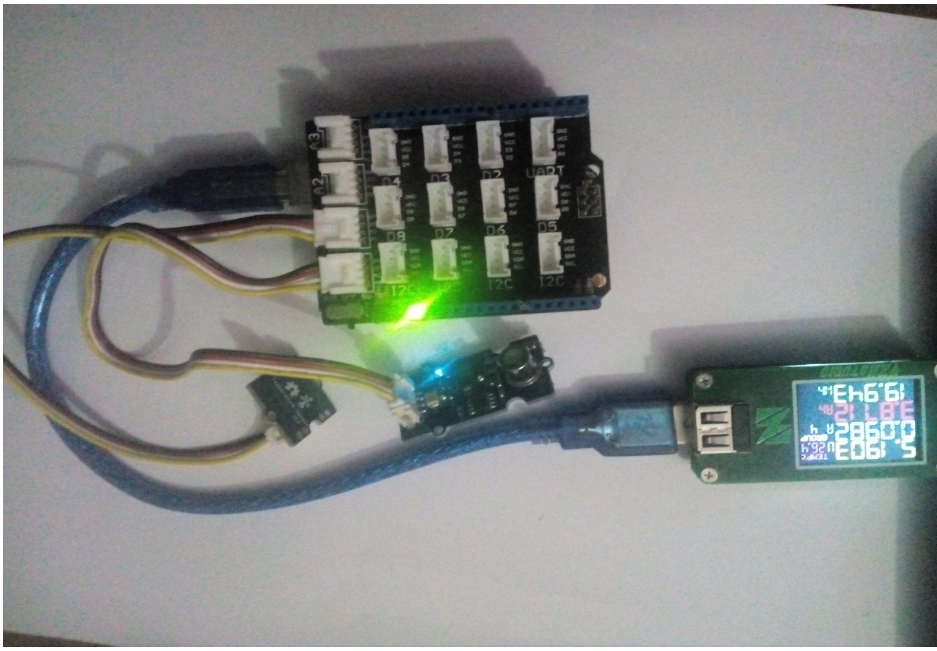

Fig. 2. Set up for Raspberry Pi 3

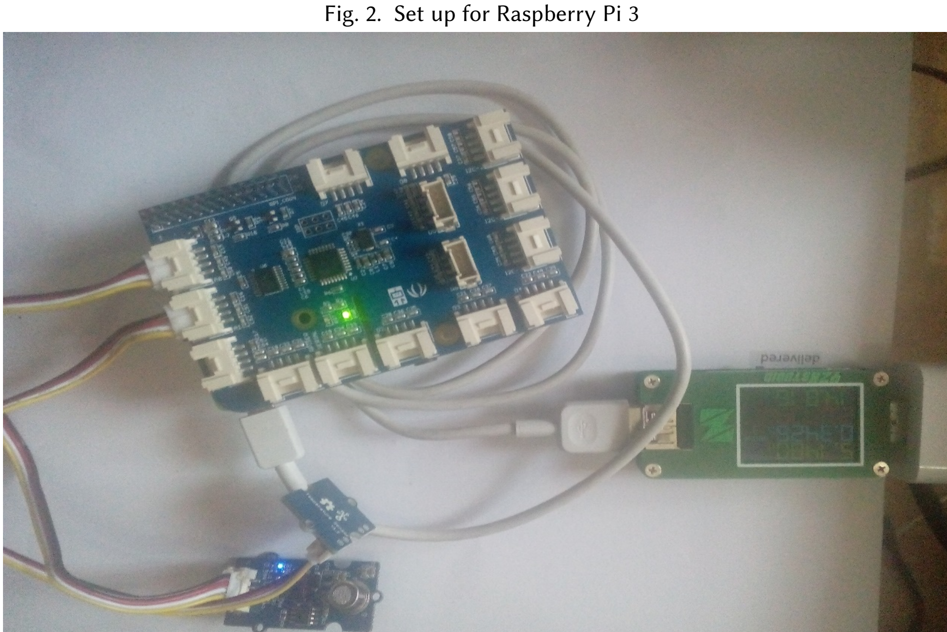

Table 5 and 6, show power consumption and AQI variables obtained during the data capture session for both systems. As it can be seen, an increase in the AQI corresponds to a decrease in

Table 3. Break down of Energy Consumption of Arduino 101

	AVG. Voltage (V)	**AVG. Current (A)**	**AVG Power(W)**
With Out Shield	5.198	0.045	0.234
With Shield	5.200	0.048	0.250
After BLE Connection	5.194	0.104	0.540

Table 4. Break down of Energy Consumption of Raspberry Pi 3

	AVG. Voltage (V)	**AVG. Current (A)**	**AVG Power(W)**
With Out Shield	5.169	0.241	1.246
With Shield	5.177	0.260	1.346
After BLE Connection	5.173	0.316	1.635

Table 5. Daily Average Energy Consumption of A101

	AVG. Voltage (V)	AVG. Current (A)	AVG Power (W)	AVG AQI
Day 1	5.188	0.104	0.537	35.560
Day 2	5.194	0.104	0.538	37
Day 3	5.190	0.099	0.516	20.490
Day 4	5.098	0.103	0.523	52
Day 5	5.176	0.104	0.536	42.460

power consumption, that can be viewed on Table 3 on the same day. The same trend can be seen when comparing Table 5 and 6, but the impact on the power consumption on the Raspberry Pi was notably less than that of the Arduino. A low value of AQI corresponds to good air quality. Thus the Arduino is more sensitive to power variations, during measurements.

Table 6. Daily Average Energy Consumption of RPi3

	AVG. Voltage (V)	AVG. Current (A)	AVG Power (W)	AVG AQI
Day 1	5.144	0.304	1.564	21.510
Day 2	5.148	0.292	1.505	20.800
Day 3	5.148	0.292	1.502	15.200
Day 4	5.148	0.292	1.504	30.981
Day 5	5.148	0.292	1.504	31.400

Table 7. Total Energy Consumption for A101 and RPI3 systems

Duration	A101		RPI3	
	PC (W)	EC (W h)	PC (W)	EC (W h)
Day 1	0.537	9.128	1.565	26.590
Day 2	0.538	9.145	1.505	25.589
Day 3	0.516	8.771	1.502	25.541
Day 4	0.523	8.895	1.503	25.567
Day 5	0.536	9.113	1.505	25.574
Total EC (W h)		45.054		128.860

As it can be seen from Table 7 the total energy consumption of the RPI3 is greater than the A101 system.

5.1 Analysis and Discussion

Table 3 and Table 4 presents the average energy consumption of an A101 and a RPI3 systems respectively. It shows that the average energy consumption of both systems in idle state stands at 0.234W h for the A101 and 1.246W h for the RPI3 without the Grove board and sensors. However, the average energy consumption of the sensor unit with a BLE connection for the A101 is slightly higher than the RPI3.

The data collection was conducted for five days. From the results in Table 7, which presents the comparison of the average daily energy consumption of both systems, it was observed that the drop in energy consumption in both systems on Day 3, was due to a change in location.

The mean energy consumption of the systems were used as the main parameter to find variation in energy consumption of both systems. In order to find difference in the mean energy consumption of both systems ANOVA (analysis of variance) was applied using = 0.05, as shown in Table 8.

At a 95% confidence interval, it can be seen that the $p - value$ is less than 0.05 (see Table 8), i.e. there is a significant difference between the mean energy consumption of the two systems. It can be seen from the results that the systems developed can be used for real-time monitoring of air quality.

6 CONCLUSION

The main goal of this paper was to compare the energy consumption between two lower power IoT boards. While the two boards are low energy devices, this in itself not sufficient to observe any

Table 8. Analysis of Variance for Energy Consumption of the Two Systems

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.430	1	2.430	5903.122	9.179×10^{-13}	5.318
Within Groups	0.003	8	0.000			
Total	2.434	9				

variation.It can be seen from the experiment that Arduino 101 based system consumes less energy on average than the Raspberry Pi 3 based system. The total observed energy consumption of the Arduino is 45.054W h, whilst that of the Raspberry Pi stood at 128.861W h approximately three times higher than the Arduino 101 system. Granted, a major consumer of the Rasperry Pi's energy is taken up in a running a fully fledged Linux Operating System, however there are sleep management boards (e.g. SleepyPi) which can periodically power down and wake the Raspberry Pi, making it a strong alternative to the Arduino which can be scheduled to power down and wake up using a watchdog timer. Based on this initial research, the next step is to run these systems continuously for prolonged periods (e.g. six months to one year) using both systems, whilst implementing various energy saving strategies. This will provide us with more data which then can be used to predict energy consumption of the systems and configure the implementation of sleep mode on the systems. More sensors for different gases and particulate matter will also be used to compare the power consumption. For example PM2.5 particulate matter sensors will be considered which may use light scattering lasers and thus would consume more energy, however are known to be good estimators of AQI.

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